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Geo-Magnetic Disturbance Analysis of HV and EHV Grids

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Geo-Magnetic Disturbance Analysis of HV and EHV Grids

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Modeling, Simulation, and Optimization for the 21st Century Electric Power Grid Conference

October 21-25, 2012
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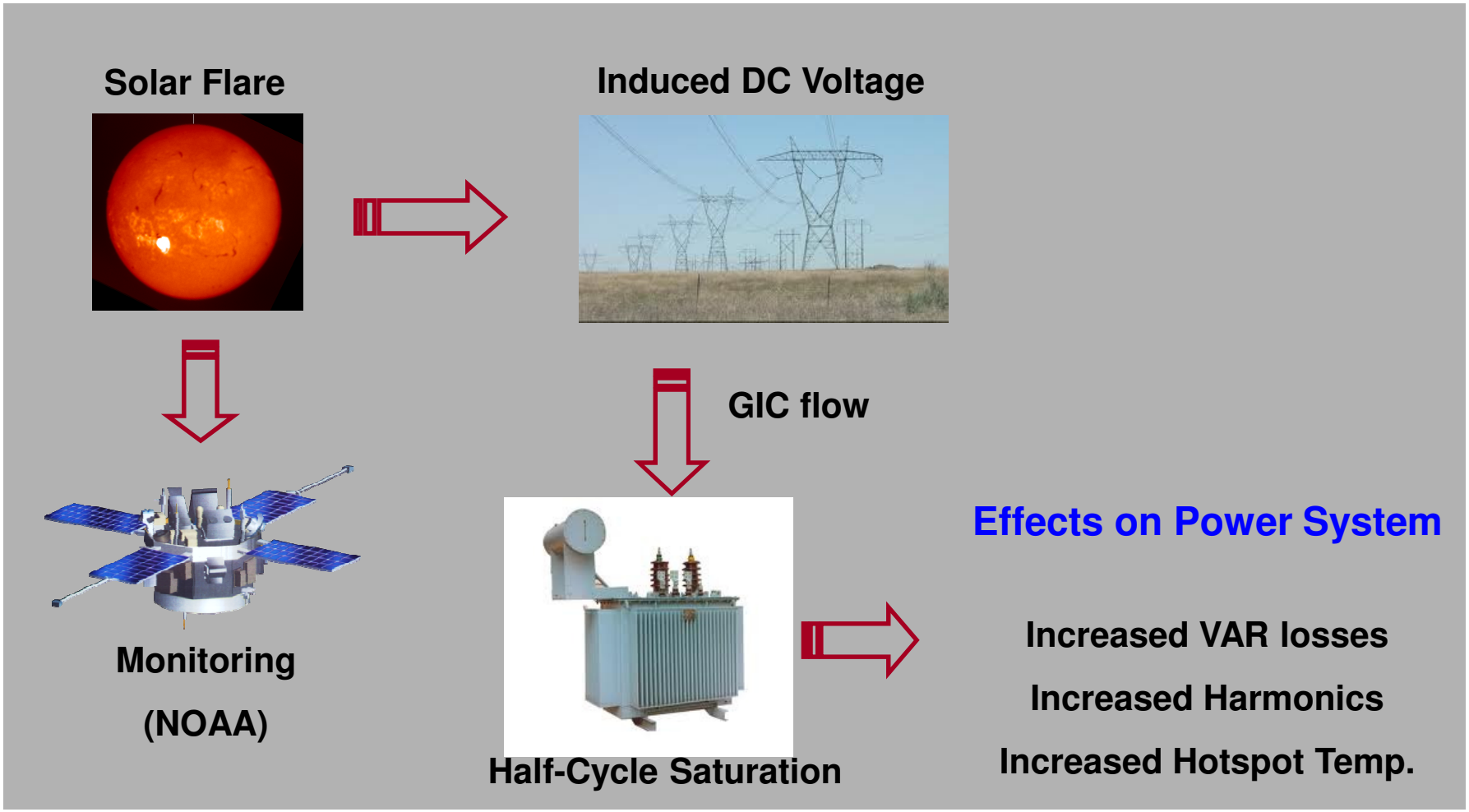
Geomagnetic Storm and Electric Power System



Source: Siemens PTI

Geomagnetic Storms

- **Solar Cycle:** maximum in solar activity that takes place approximately every eleven years
  - Large geomagnetic storms can occur with smaller cycles.
  - The largest geomagnetic storms on record occurred during smaller-than-average cycles.
- **Electric utilities need to plan not only for Solar Cycles, but any GMD event that can occur.**
- **Electric utilities will have hours to 2-day advance notice of geomagnetic storm. [NOAA Space Weather Prediction Center (SWPC)]**

Overview of GMD Research Activities

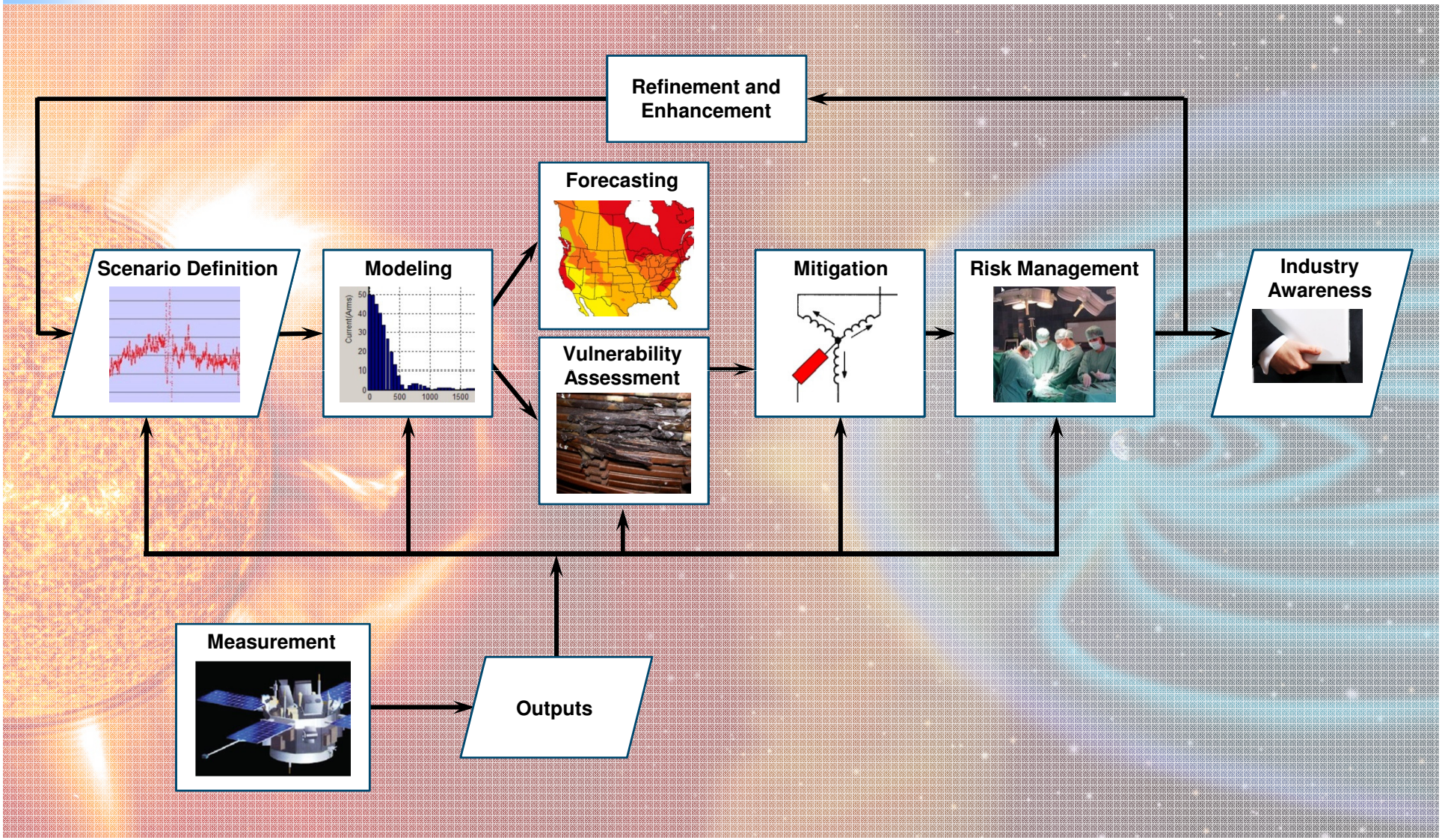


Photo Sources: NOAA Space Weather Prediction Center; SOHO (ESA & NASA)

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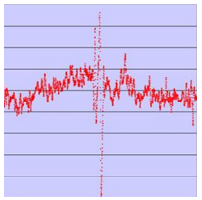
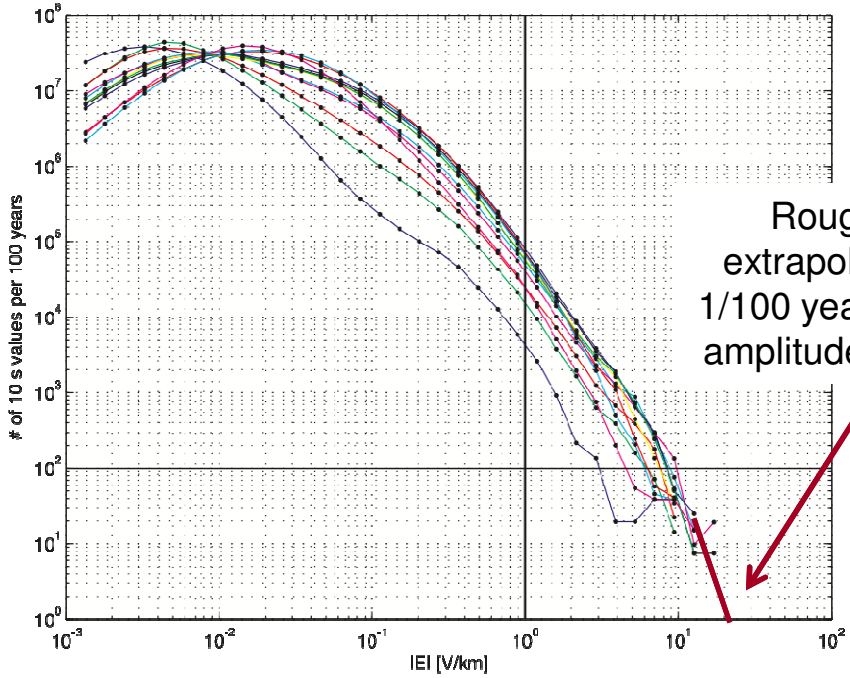
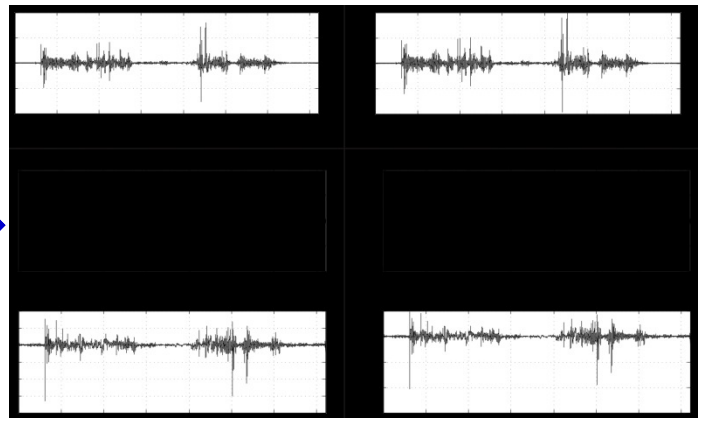
Creating Scenario Definition



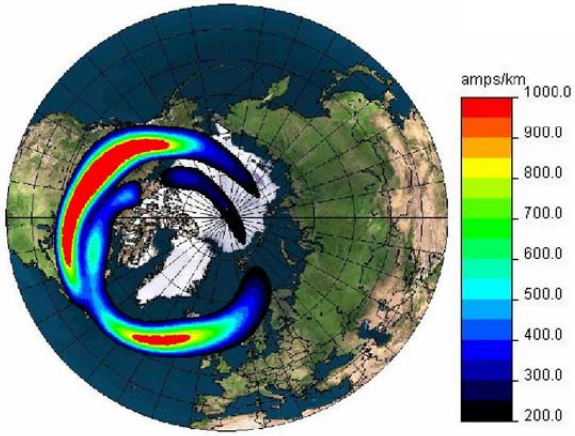


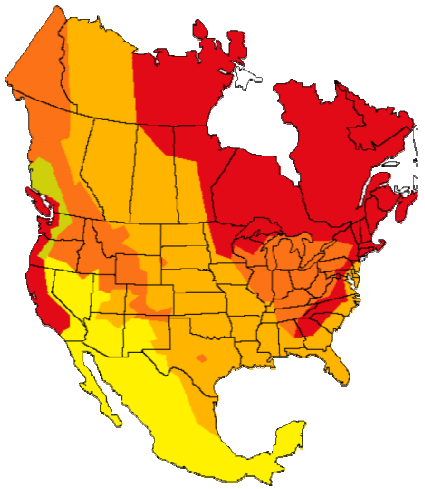
Rough visual extrapolation gives 1/100 year 10-second amplitude of 20 V/km

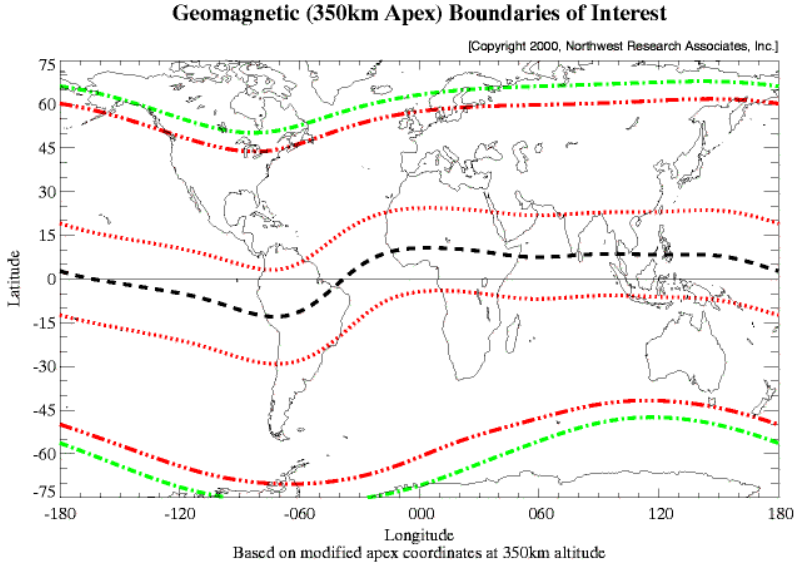


Source: Statistical Occurrence of Modeled Geoelectric Field in Quebec (*Pulkkinen et al.*, 2008)

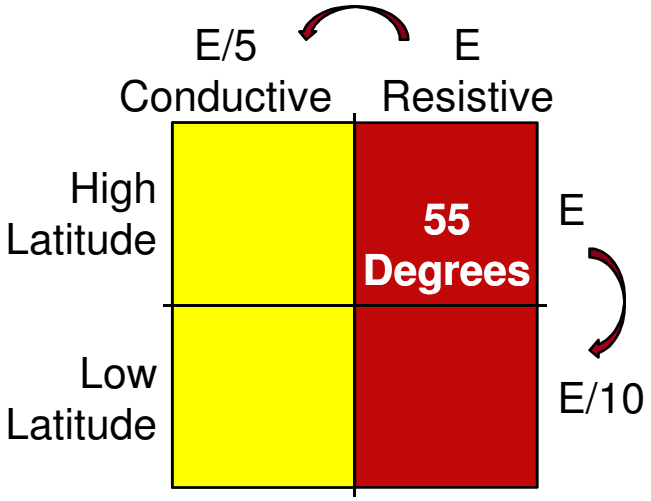
Effect of Latitude and Geology on Electric Field Gradient







Geo-Magnetic Latitude Contours



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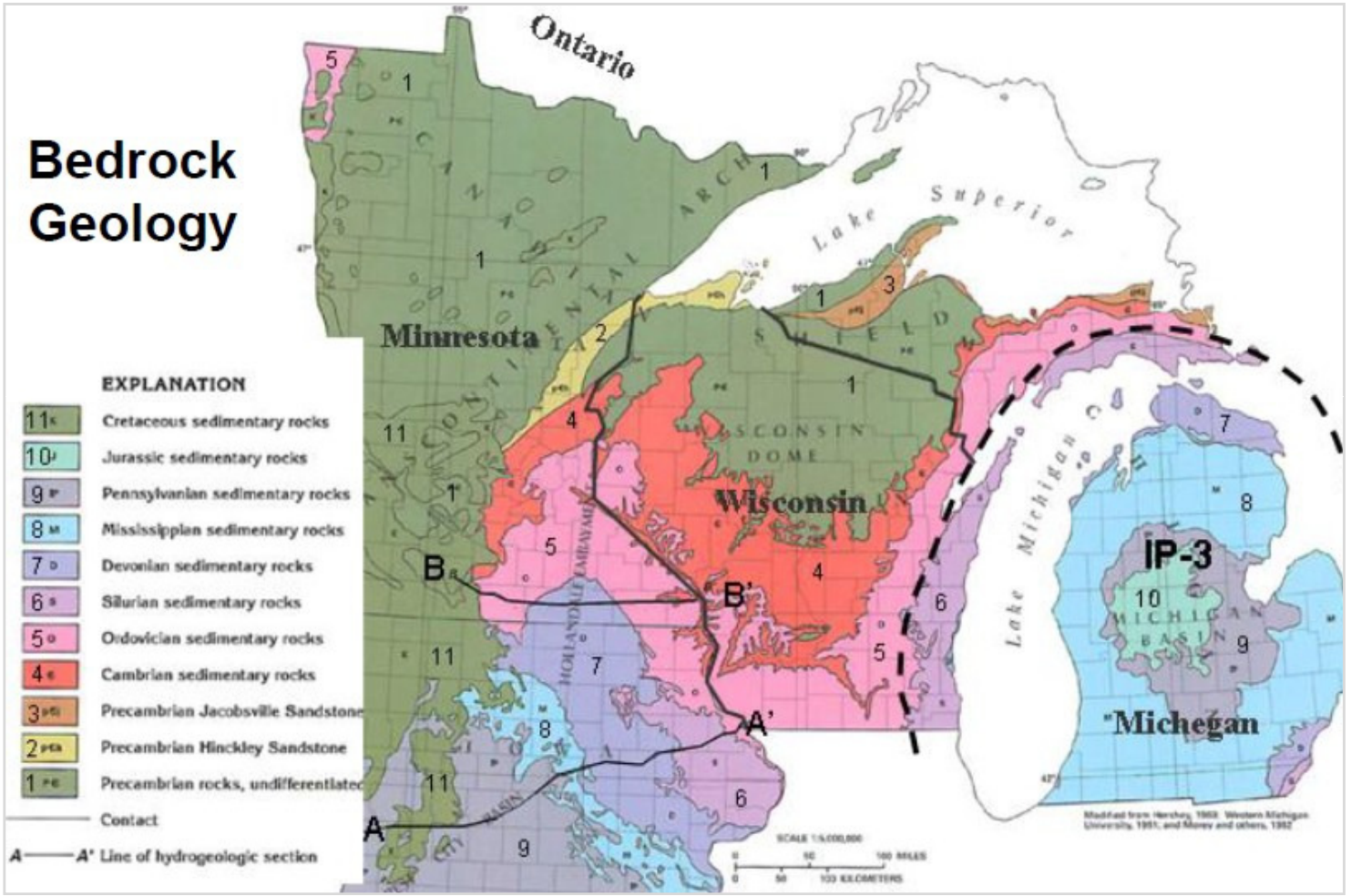
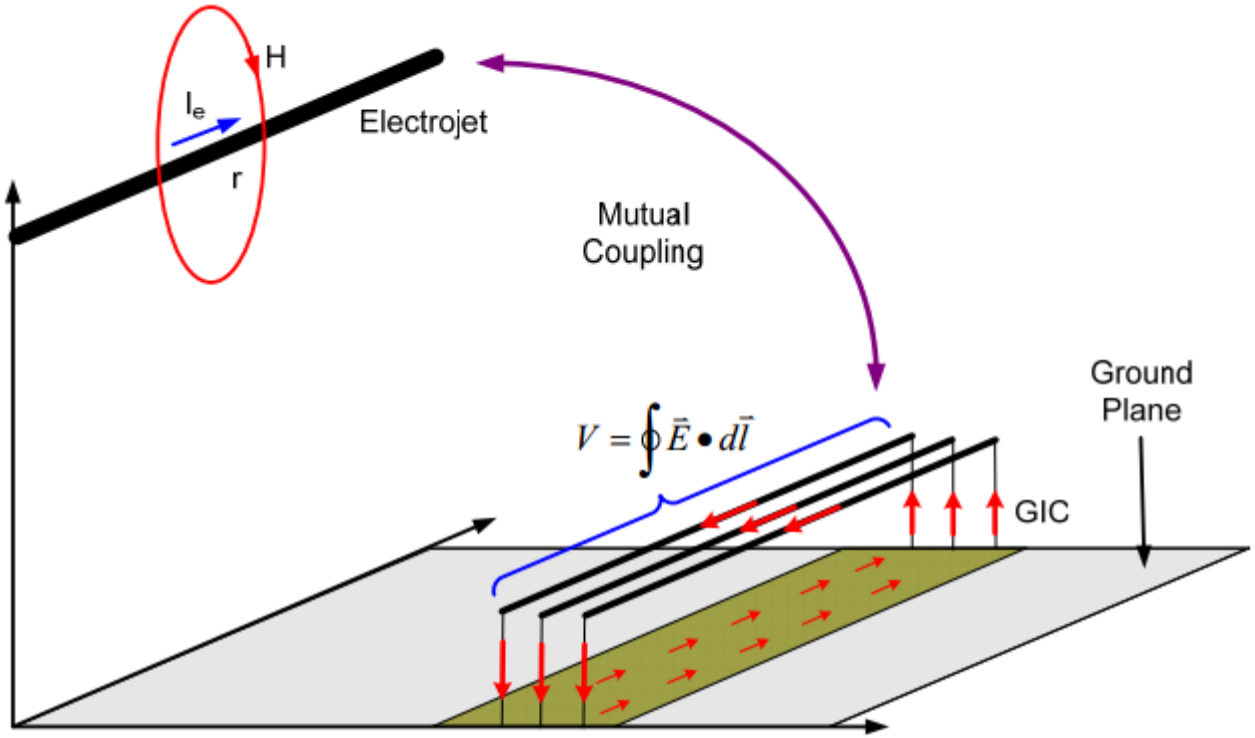
Geology

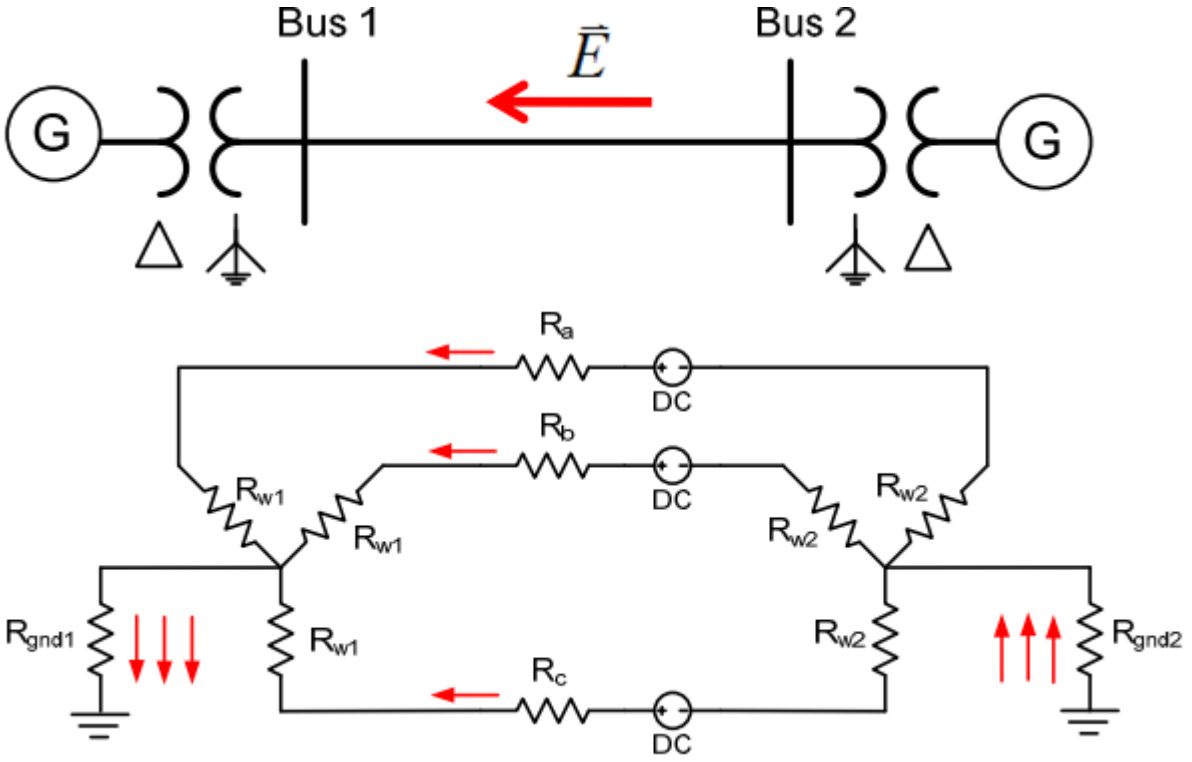


GIC Induced from GMD Activity

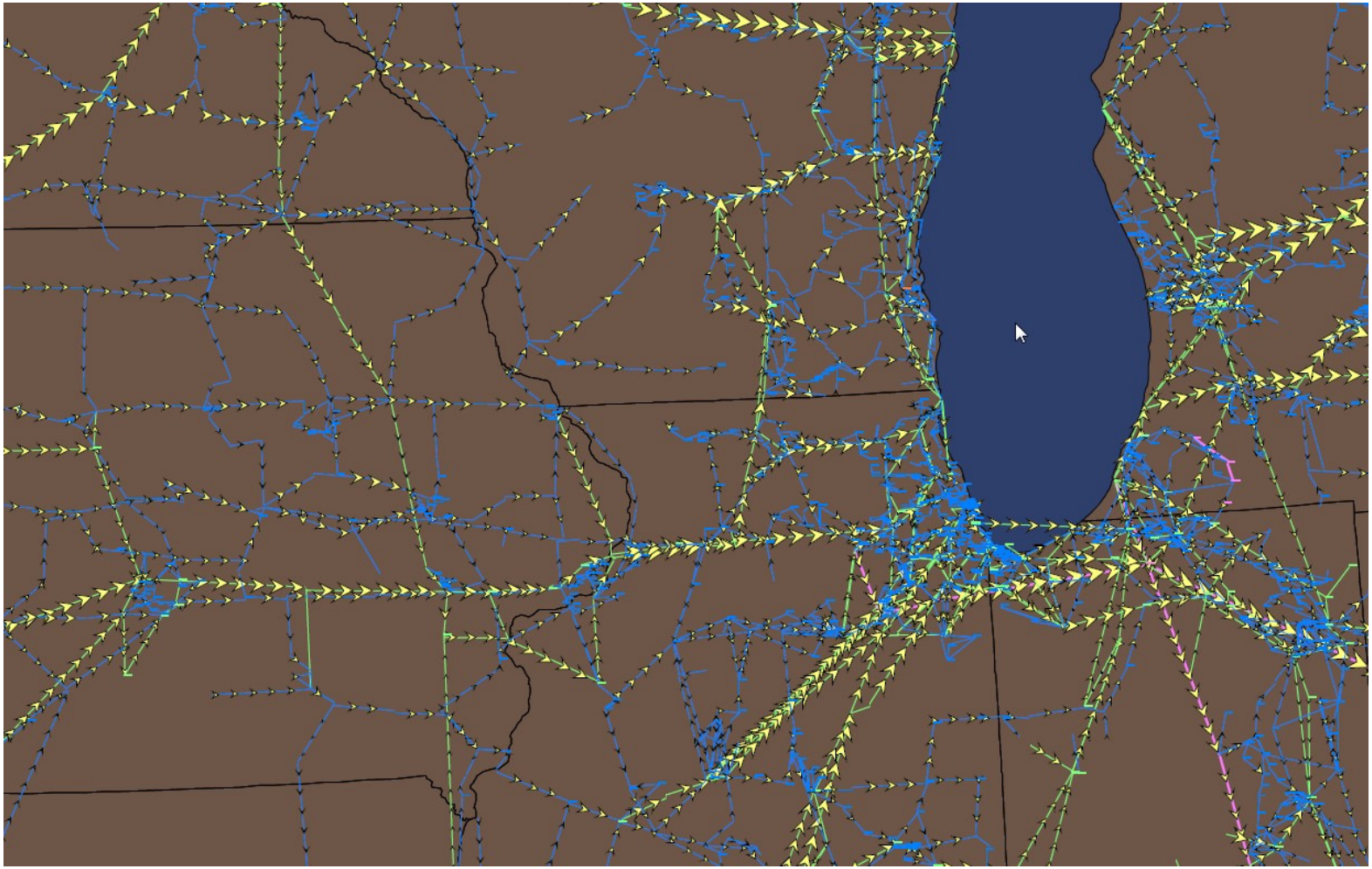


Source: National Weather Service, NERC GMD Workshop 2011 Report

GIC Conduction Paths

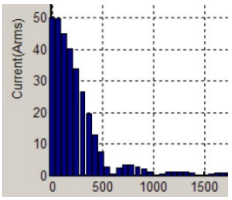


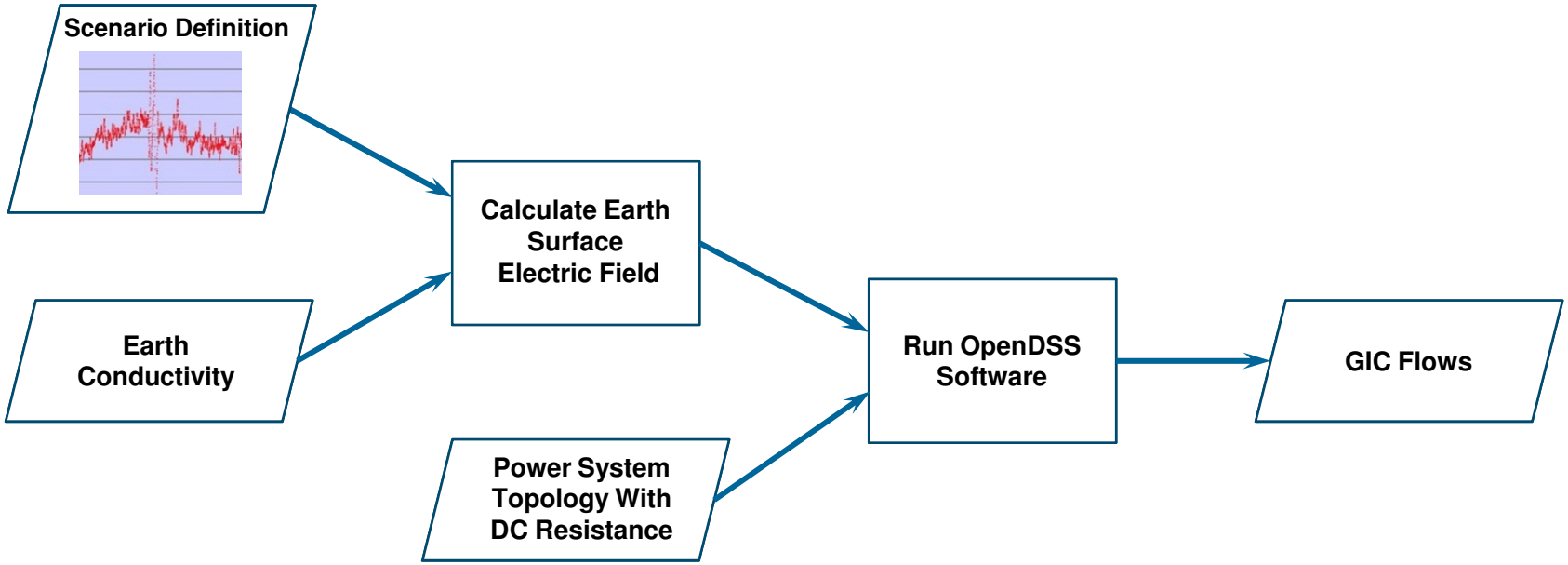
Drivers of GIC Flow



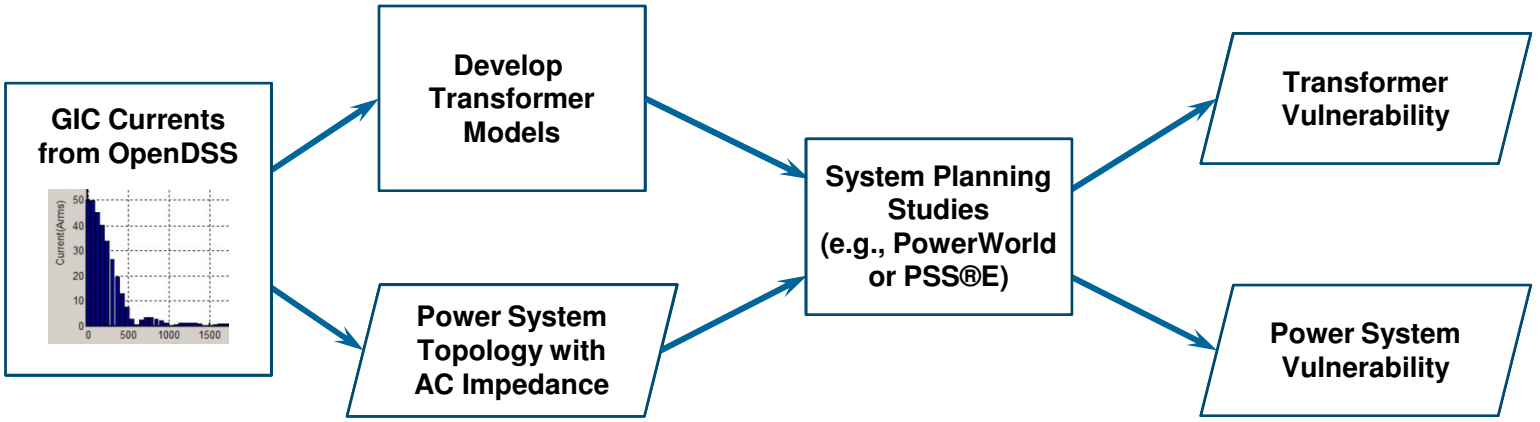
(PowerWorld Display)

Modeling of GIC Flows

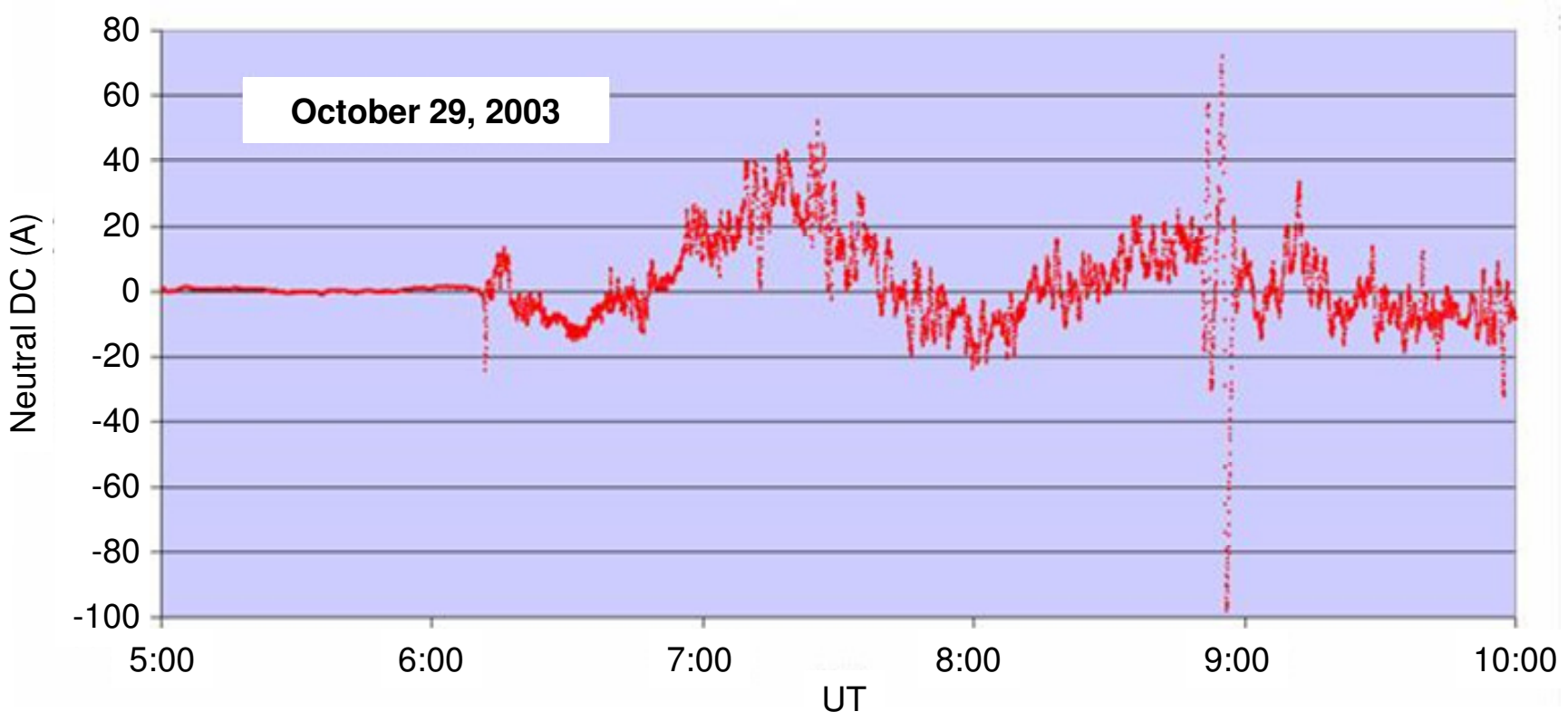




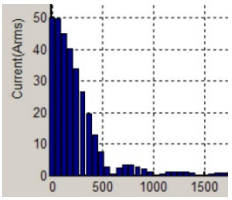
System Planning Studies for Vulnerability Assessment



Sunburst Network GIC Measurement: Halloween Storms of 2003



Developing and Validating Transformer Models



OpenDSS (GIC): Predicted GIC

Sunburst Measurement Network: Actual GIC

Develop detailed model of one or two transformer types

Ex: 3-phase, 3-limb, core type, Model ABC

Electrical Thermal

Ex: 3-phase, 7-limb, core type, Model XYZ

Electrical Thermal

Test actual transformers to validate modeling methodology (Measure harmonics, VARS, temperature, etc.)

3-phase, 3-limb, core type, Model ABC

3-phase, 7-limb, core type, model XYZ

For each transformer type, model a handful of different transformers of that type (e.g., variations in number of turns, cooling systems, etc.)

3-phase, 3-limb, core type, Model ABC
Model DEF
Model GHI

3-phase, 5-limb, core type, Model JKL
Model MNO
Model PQR

3-phase, 7-limb, core type, Model STU
Model VWX
Model AAB

Filter these models – Select the most conservative result for each type for system modeling and transformer vulnerability analysis

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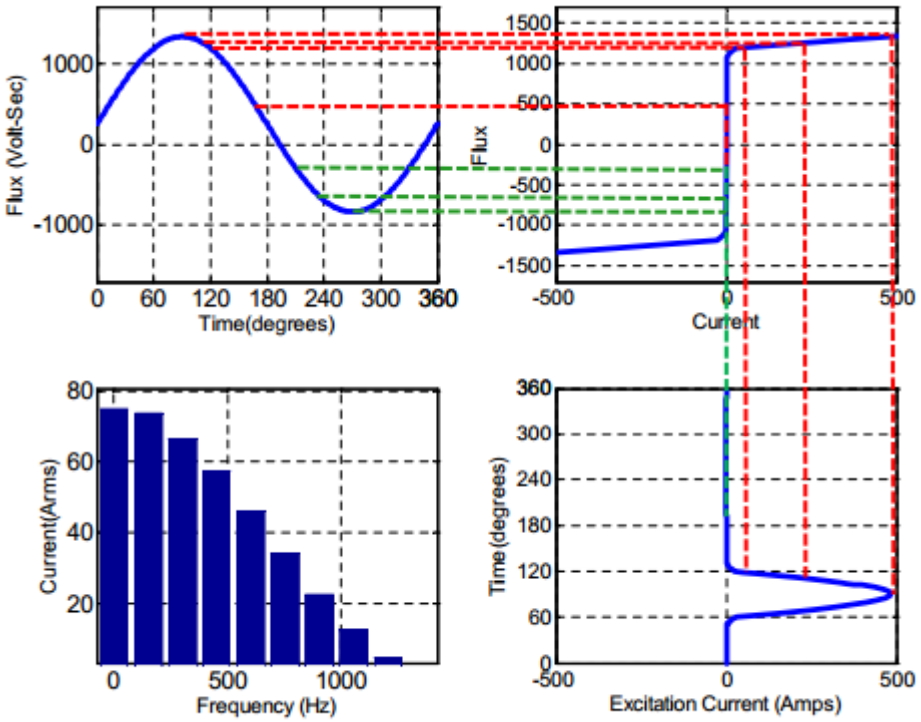
Transformer Half-Cycle Saturation from GIC



NERC GMD Workshop April 2011

Harmonics

Heating

Increased Vars

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GIC Test Case

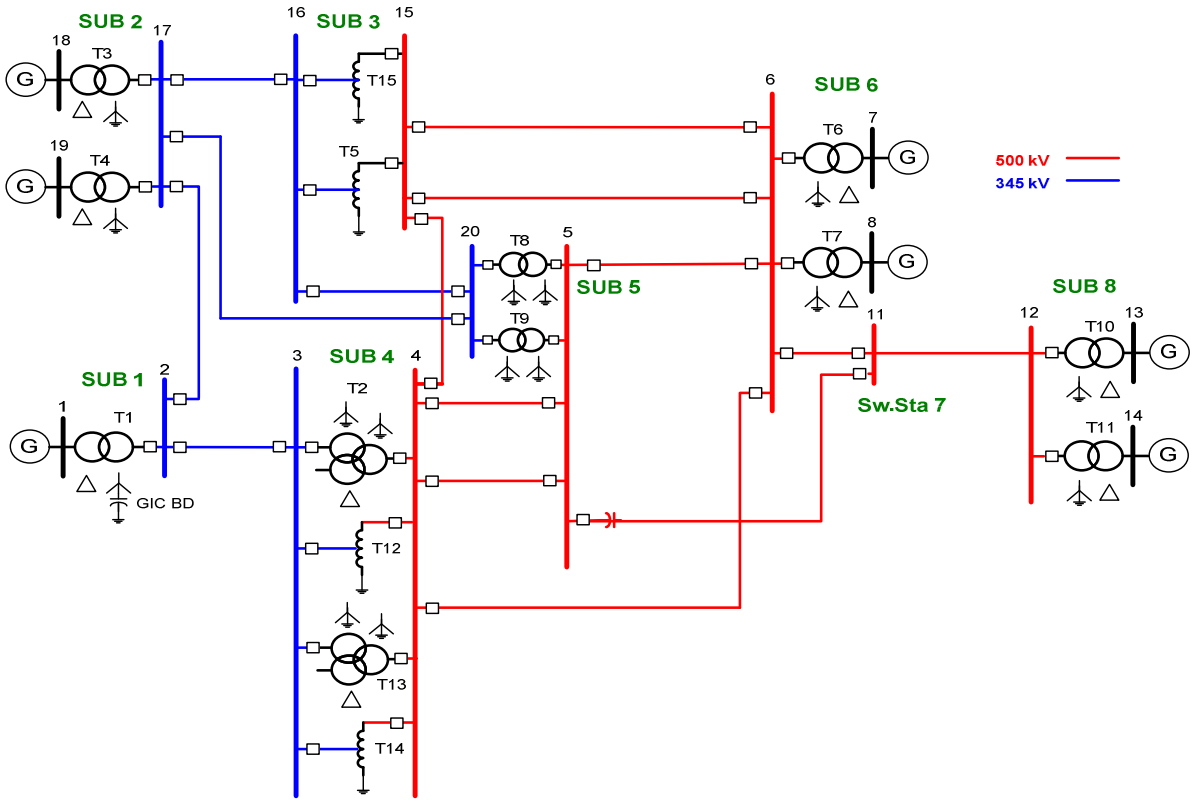
IEEE Trans. on Power Delivery – Oct 2012

A Test Case for the Calculation of Geomagnetically Induced Currents

R. Horton, *Senior Member, IEEE*, D. H. Boteler, *Senior Member, IEEE*, T. Overbye, *Fellow IEEE*, R.J. Pirjola, R. Dugan, *Fellow, IEEE*

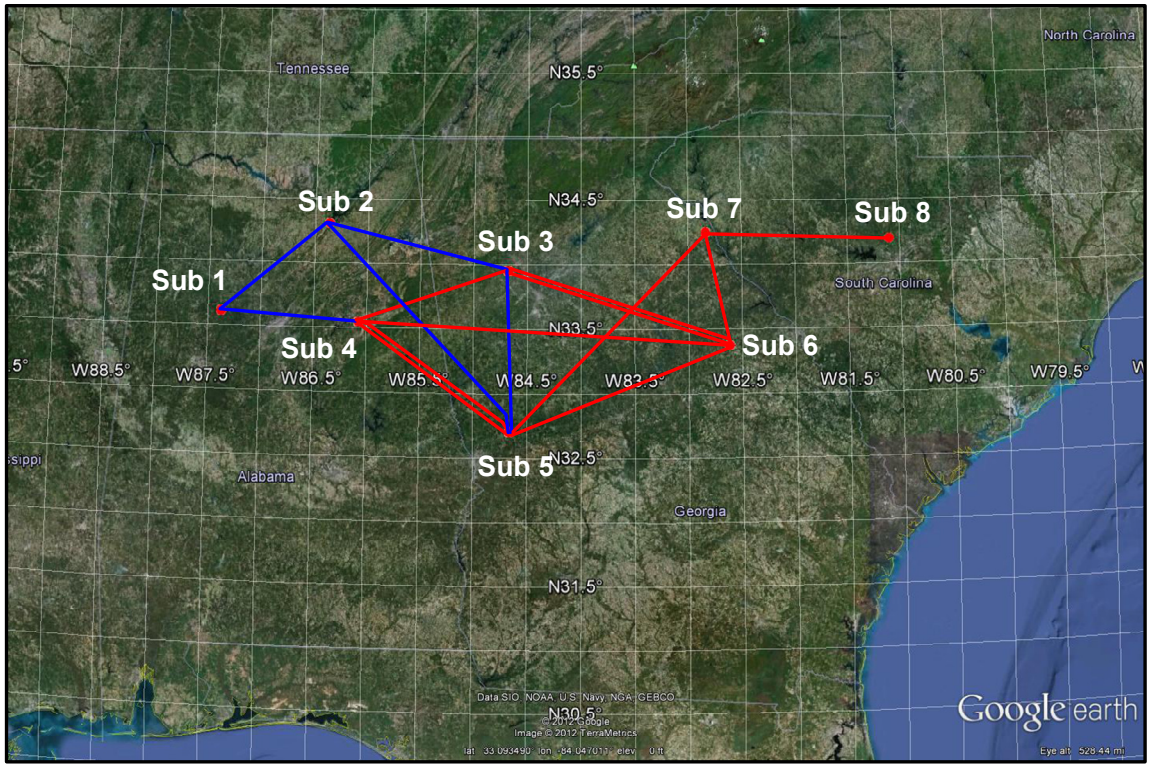
***Abstract*--Geomagnetically induced currents (GICs) in power systems can attribute to problems ranging from transformer overheating, misoperation of protective relays and voltage instability. Assessment of the geomagnetic hazard to power systems requires accurate modeling of the GICs that are expected to occur. However, to date, there are no publicly available test cases to validate software programs used to compute GIC. The following paper presents a hypothetical network that can be used as a test case for validating results from GIC modeling software. The network contains many features found in real networks such as: different voltage levels, two and** test cases to validate software [8], no IEEE test case exists to validate GIC modeling software. To facilitate the testing and comparison of GIC modeling procedures, a benchmark test case is presented. The details of the test case are designed to: 1) include many features found in typical high voltage (HV) and extra high voltage (EHV) networks, and 2) show the results obtained with four independent software programs. To aid those involved in the software validation process, the values obtained at key points in the calculation process are also presented.

GIC Test Case – One Line Diagram



Purpose: Provide a benchmark for software tools that compute GICs in HV/EHV networks

GIC Test Case – Hypothetical Geography



500 kV

345kV

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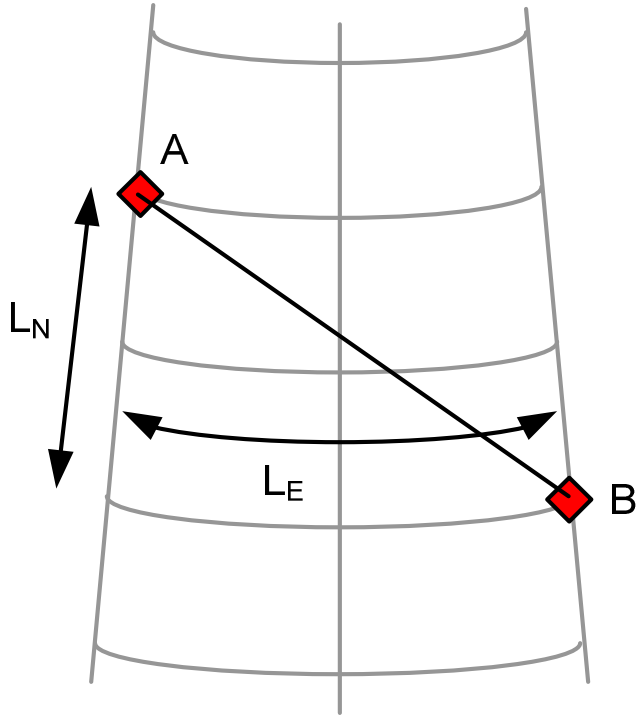
Compensating for Earth Curvature

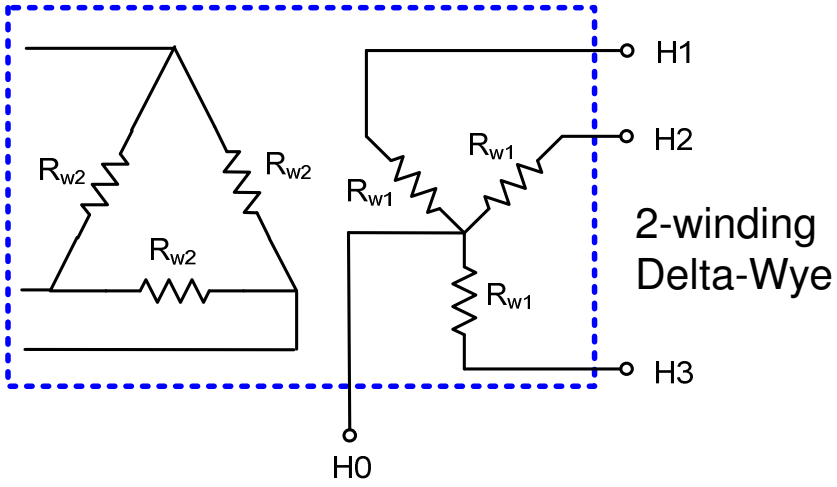


$$V = E_N L_N + E_E L_E$$

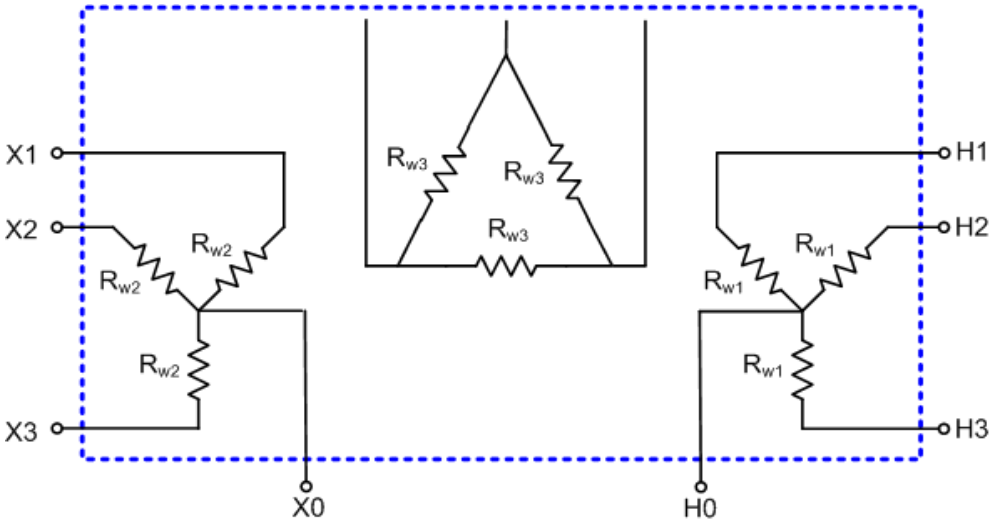
$$L_N = \left(111.133 - 0.56\cos\left(2\phi\right)\right) \cdot \Delta lat$$

$$L_E = \left(111.5065 - 0.1872\cos 2\phi\right) \cdot \cos\phi \cdot \Delta long$$

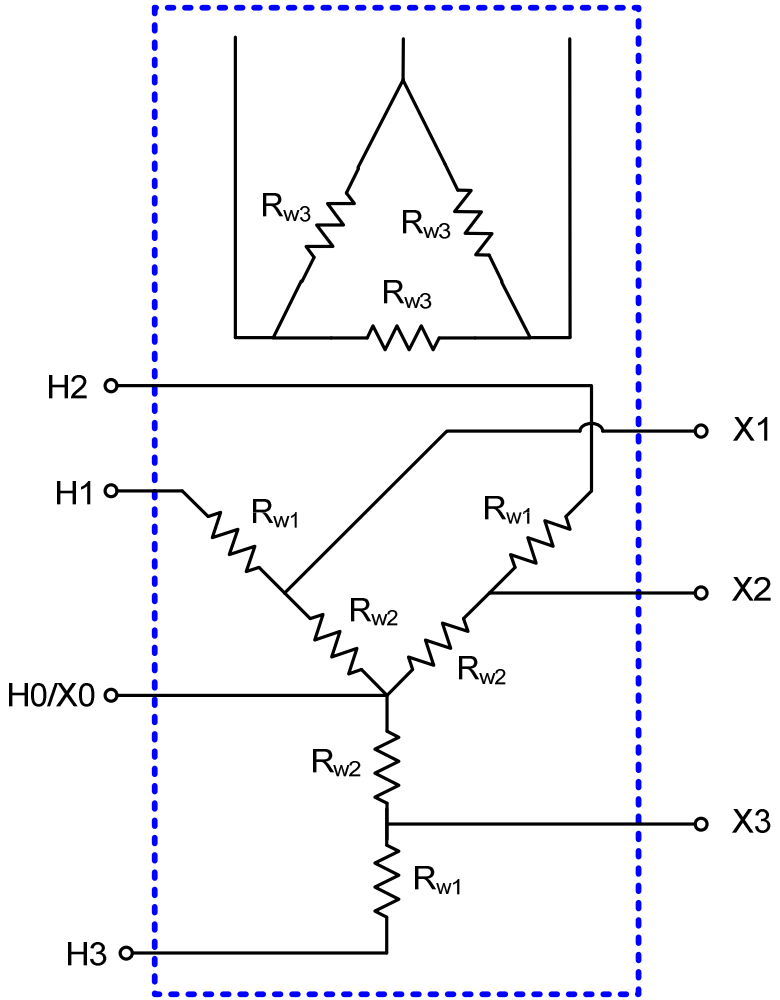
Special Models for GIC Calculation - Transformers



2-winding Delta-Wye

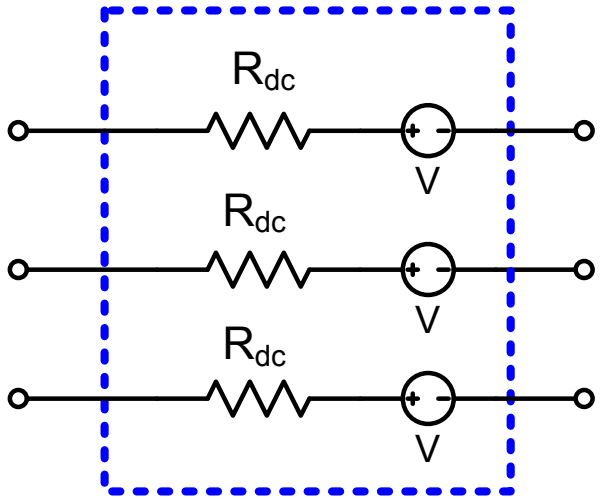


3-winding Wye-Delta-Wye



Autotransformer w/ Delta Tertiary

Special Models for GIC Calculations - Lines



GMD source appears in series with line resistance

$$V = E_N L_N + E_E L_E$$

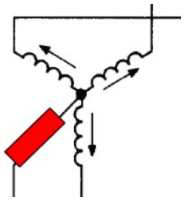
OpenDSS Simulations are performed at 0.1 Hz

OpenDSS Script

- GIC Test Case is provided with the standard installation
  - www.Sourceforge.net
  - Search for OpenDSS
- Described in the User Manual (snippet of script):

```
!GIC Line Data¶
New GICLine.1-Bus2-Bus3 bus1=2 bus2=3 R=3.512 Lat1=33.613499 Lon1=-87.373673
Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00¶
New GICLine.2-Bus2-Bus17 bus1=2 bus2=17 R=3.525 Lat1=33.613499 Lon1=-87.373673
Lat2=34.310437 Lon2=-86.365765 EE=1.00 EN=0.00¶
New GICLine.3-Bus15-Bus4 bus1=15 bus2=4 R=1.986 Lat1=33.955058 Lon1=-84.679354
Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00¶
New GICLine.4-Bus17-Bus16 bus1=17 bus2=16 R=4.665 Lat1=34.310437 Lon1=-
86.365765 Lat2=33.955058 Lon2=-84.679354 EE=1.00 EN=0.00¶
New GICLine.5-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605
Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00¶
New GICLine.6-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605
Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00¶
```

Mitigating GMD Effects



Timeframes:
1. In Advance
2. Warning (a few days)
3. Alert (hours)

Define Optimal Operating Strategies (1, 2, 3)

Model Best Practices: "What-if?" Analyses Using OpenDSS (GIC) and Power Flow Models

Define and Assess Hardware Retrofits (1)

Define Equipment Procurement Standards (1)

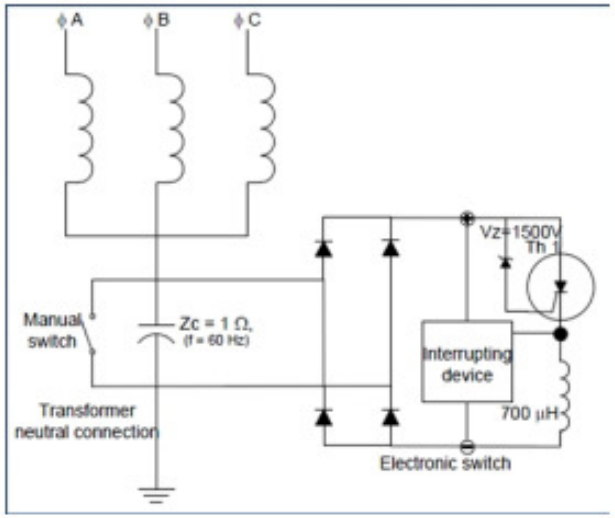
Spares Strategies (STEP, RecX, SEDTF) (1)

Assess Effectiveness in Actual GMDs

Integrate Into Risk Management Strategy

Refine and Prioritize

Neutral Blocking Capacitors



Hydro-Quebec Transenergie Interconnection

Questions?

Together…Shaping the Future of Electricity